DEPARTMENT SUMMARY

The Oceanography Department has developed a broad research program focused on physical oceanography to meet the anticipated future needs of the Navy. The priority basic research themes are the development of scientific capabilities to measure, analyze, and forecast fields of littoral ocean variables which occur in association with synoptic/mesoscale processes over limited regional and temporal domains. The areas of emphasis include coastal and nearshore ocean dynamics, air-sea interaction phenomena, and boundary currents. Regions of interest include the marginal sea ice zone, coastal ocean regions, and strategic straits of the world.

The priority applied research themes are the application of analyses and forecasts of upper ocean synoptic/mesoscale variability to Naval operations. Areas of emphasis include the impact of littoral processes, eddies, and boundary currents on ocean surveillance systems, the effect of coastal ocean response storms on acoustic propagation's and ambient noise and the impact that the wave climate exert on nearshore processes and beach character as pertains to mine/mine countermeasure, amphibious warfare, and special forces operations.

These research themes require the development of numerical ocean prediction and synoptic oceanography capabilities. They are achieved through employment of modern dynamical and mathematical principles, numerical and statistical methods, computational and graphical facilities, and in-situ and remote sensing observation.

The diverse talents of the faculty of the department are blended by the use of these various techniques to solve problems of common interest. The students are actively involved in these research programs and participate in research cruises, conference presentations, and as co-authors of research reports and papers. Much of the research results, both theoretical and applied, are incorporated into the curricula we support. A summarization of particular research areas follows below.

COASTAL AND NEARSHORE OCEANOGRAPHY

Under sponsorship of the Office of Naval Research (ONR), Associate Professor M.L. Batteen is using an eddy-resolving, primitive equation coastal model to study the generation, stability, and maintenance of currents and eddies in the California and Iberian Current Systems.

Professor C.A. Collins, working with Professors N. Garfield, R. Paquette and E. Carter, continued investigations of the California Inshore Current (CIC). The seasonal cycle of currents off Pt. Sur, California, was resolved: flow was poleward year round, with maximum flow in spring. The structure of the flow at the entrance to the Gulf of California was also resolved and it appears that CIC waters may be ventilated within the Gulf. Lagrangian studies of the structure of the CIC resulted in the discovery of a "new" mechanism for salt dispersion: submesoscale coherent vortices which have been termed "cuddies." These Lagrangian studies also showed that the alongshore flow can be coherent over distances of 400 Km.

Associate Professor P.C. Chu and Professor R.H. Bourke, under the sponsorship of the Office of Naval Research, have determined the coherent time and length scales of the temperature and salinity field in the Beaufort Sea using the complete historical hydrographic database for the Beaufort Sea. This research is in support of the field program and modeling effort associated with the Surface Heat Budget of the Arctic Ocean (SHEBA) Experiment.

Associate Professor P.C. Chu, under the sponsorship of the Naval Oceanographic Office, has developed a parametric model for regional sea T, S data analysis, quantitatively determined temporal and spatial thermohaline variability, and established a diagnostic model for the regional seas, e.g., the South China Sea, the Japan Sea, and the Yellow Sea. He has developed an optimization method to determine the open boundary conditions of coastal models.

Associate Professor P.C. Chu**,** under the sponsorship of the Office of Naval Research, has developed several high-order difference schemes which will increase the accuracy of ocean models, especially the sigma coordinate ocean models with abrupt topography. Under separate funding, he developed a statistical model to identify the South China Sea warm-core and cool-core eddies, a new technique (S-transform) for obtaining localized spectra has been developed and validated, a parametric model for obtaining physical characteristics (SST, mixed layer depth, thermocline depth and thermocline strength) from vertical profiles.

Associate Professor P.C. Chu, Professors R.H. Bourke, and C.A. Collins, under the sponsorship of NPS, have tested the sensitivity of the Navy's Research, Evaluation, and Systems Analysis (RESA) wargame to the environment. At the same time, they are incorporating realistic environments into high-resolution, high fidelity wargames of mine warfare.

Under the sponsorship of the Navy Engineering Logistics Office, Professors N. Garfield and R. Olsen, Department of Physics, are conducting an investigation of nearshore bathymetric estimates derived from hyperspectral visible and infrared data.

Associate Professor T.H.C. Herbers**,** is investigating the dynamics of ocean surface waves in shallow coastal waters using theory and field observations. Current research projects (funded by the Office of Naval Research) focus on nonlinear wave-wave interactions, shoaling of waves on beaches, the generation of surf beat, and the propagation of waves over a continental shelf.

Research Associate Professor L. Ly in cooperation with Dr. P. Luon**g** (NAVOCEANO), under multi-year sponsorship of the Office of Naval Research Navy Ocean Modeling and Prediction Program (NOMP), developed a Coastal Ocean System (COS) with curvilinear nearly-orthogonal, multi-block grids, which better handle complicated coastlines, bathymetry and open boundary conditions. The generated numerical grids were coupled to the coastal ocean models with data assimilation schemes. Under the sponsorship of ONR NOMP, Professors L. Ly, J. Paduan and Dr. P. Luon**g** (NAVOCEANO) use the Monterey Bay COS to study the response of MOB to diurnal wind and tidal forcing.

Associate Professor J.D. Paduan, with funding from the Office of Naval Research (ONR) and the National Science Foundation (NSF) is undertaking studies of coastal circulation problems in Monterey Bay, CA and off Chesapeake Bay, VA, using high frequency (HF) radar-derived currents. Of particular interest are the coastal phenomena of sea-breeze driven currents related to sea-land temperature differences and internal tidal currents generated when sea level fluctuations interact with the sloping ocean bottom. A primitive-equation modeling study is also underway using the Princeton Ocean Model to simulate the three-dimensional generation and propagation of internal tides around the Monterey Submarine Canyon.

Assistant Professor P.-M. Poulain has started to make direct measurements of the surface currents in the Strait of Sicily and the Ionian Sea using satellite-tracked drifters in order to describe the variability of the surface circulation mesoscale structures and gain knowledge on their dynamics. This project, in close collaboration with NATO/SACLANTCEN and Italian research institutes, is sponsored by NPS.

Under the sponsorship of NAVO, Professors C.A. Collins and P.-M. Poulain have developed digital layers of information about currents in the Adriatic Sea that will be tactically useful for mine warfare operations.

Research Associate Professor L. Rosenfeld is studying internal waves, particularly at tidal frequencies, in the littoral zone. She is working with Professor Paduan on model studies funded by ONR, and is making field measurements, funded by NSF with colleagues from the University of Washington.

Professors E.B. Thornton and T.P. Stanton are developing models to predict the wave-induced three-dimensional velocity field and induced sediment transport over arbitrary bathymetry in the nearshore zone, and comparing the models to comprehensive field data. They participated in the two-month extensive nearshore field experiment SandyDuck. This work is sponsored by ONR. Under a separate ONR contract, they are evaluating their wave and current surf zone models that have been transitioned to the fleet Tactical Environment Support System.

ACOUSTICAL OCEANOGRAPHY

Professors R.H. Bourke and J.H. Wilson are analyzing bottom backscattering data from shallow water areas with a goal of developing a bottom reverberation algorithm for the AN/SQS-53C sonar when operating in shallow coastal waters. They have recently expanded this research to include the new helicopter sonar (ALFS) and the low frequency active (LFA) sonar. Investigations in the past year have centered on quantifying the energy spreading loss phenomenon. The Sponsors are Naval Undersea Warfare Center (NUWC), Space and Naval Warfare Systems Command (SPAWAR), and Naval Air Systems Command (NAVAIR).

Professors R.H. Bourke and J.H. Wilson are developing a predictive ambient noise model for submarines operating in the Arctic Ocean which will forecast periods of extremely loud (>95th percentile level) and quiet (<5th percentile) noise levels. The ice prediction model, PIPS, is being modified to produce output fields of energy disruption as an indicator of pressure ridge formation. They are also studying RADARSAT imagery to verify the response of the ice deformation field to windforcing. The sponsor is ONR.

Professor C.-S. Chiu is conducting an integrated oceanographic-acoustic field study in the Mid-Atlantic Bight in collaboration with Woods Hole Oceanographic Institute and Harvard University. The research is designed to study the influence of shelf-slope ocean mesoscale processes on the propagation of sound from the continental slope onto the continental shelf. In a separate program, the vertical structure, generation, propagation, spectral characteristics, and acoustic effects of the nonlinear internal solitons on the New Jersey shelf are being studied. Data for the study were measured in the 1995 Shallow Water Acoustic Random Medium Experiment (SWARM 95). The work is funded by ONR.

Professor C.-S. Chiu and the staff of the Coastal Ocean Acoustic Center are continuing the development of the Pt. Sur Ocean Acoustic Observatory. The objectives are to preserve the functionality of the Pt. Sur SOSUS horizontal hydrophone

array and to convert the facility into a dual-use Ocean Acoustic Observatory for the purpose of undersea research. The development is sponsored by University of Washington Applied Physics Laboratory, Center of Monitoring Research, Monterey Bay Aquarium Research Institute, Naval Postgraduate School, and Cornell University.

Professor C.-S. Chiu organized the International Conference on Shallow-Water Acoustics with the Institute of Acoustics of the Chinese Academy of Sciences and Georgia Tech. This conference was held in Beijing, China, in April 1997 and represents a follow-on to the first joint USA-China Conference in Shallow-Water Acoustics convened and chaired by Professor Chiu in 1995. An important goal of these international meetings is to plan an international shallow-water acoustics experiment in the South China or Yellow Sea for 1999. The work is funded by ONR.

Assistant Professor K.B. Smith and Professor C.-S. Chiu are investigating time-domain acoustic signal processing and propagation modeling techniques for the localization of sources of acoustic transient signals. The research is funded by NUWC.

AIR-SEA INTERACTION AND OCEAN TURBULENCE

Professor L. Ly developed an air-wave-sea interaction model of semi-empirical turbulence and similarity theories. The model was used in the modeling of vertical distributions of turbulent dissipation in the Upper Oceanic Turbulent Layer under surface breaking wave conditions. This work was under multi-year sponsorship of ONR.

Professor R.W. Garwood is sponsored by ONR to simulate the response of Lagrangian drifters, buoys, mines and AUVs to oceanic flows and turbulence in the Labrador Sea. This project is part of a five-year accelerated research initiative (ARI) of the Office of Naval Research to observe and model deep convection in the Labrador Sea.

Ms. Arlene Guest and Professor Garwood have a four-year grant from the National Oceanic and Atmospheric Administration (NOAA) and National Science Foundation (NSF) for the project,"Equatorial Mixed Layer System." This project is part of the TOGA Coupled Ocean Atmosphere Response Experiment (COARE), to explain large-scale feedback between the ocean and atmosphere in the Western Pacific.

Professor R.W. Garwood is also funded by the National Science Foundation with a new four-year grant to study Polar Sea convective instabilities and deep-water formation.

Research Associate Professor T.P. Stanton, participated in the first open ocean iron enrichment experiment under ONR sponsorship by designing a Lagrangian reference frame for the experiment and defining mixed layer processes which contribute to the dispersion of surface injected tracers. Under National Science Foundation sponsorship, he participated in the Antarctic ANZFLUX program by deploying three instrument systems which measured anomalously high winter heat fluxes across the ocean mixed layer in the Weddell Sea. He also participated in the ONR/NOAA sponsored COPE experiment by defining the upper ocean mixing contributed by highly non-linear solitons on the continental shelf. He is currently participating in the NSF-sponsored Surface Heat Budget Program, SHEBA, in the Arctic Ocean.

Professors T.P. Stanton and E.B. Thornton are measuring dissipation of shoaling surface gravity waves over the continental shelf in the new five-year ONR sponsored "Shoaling Waves."

NUMERICAL PREDICTION AND DATA ASSIMILATION

Under sponsorship of NSF, Associate Professor Batteen is carrying out eddy-resolving, modeling studies of the Leuuwin Current in the coastal region off Western and Southern Australia. Process-oriented studies are being used to explore the roles of thermal and wind forcing, coastline irregularities, and topography in the generation, stability, and maintenance of the currents and eddies in this anomalous eastern boundary current region.

Professor A.J. Semtner, Jr., under National Science Foundation sponsorship, has developed a global eddy-resolving ocean model with 1/4 degree grid size. Comparisons with in-situ and satellite observations show the simulation to be very realistic, hence the model provides a means of improving physical understanding of the ocean and enabling climate change prediction. In another project funded by the Department of Energy, developmental studies are underway to incorporate all the relevant physical processes (including sea ice and a surface mixed layer) important to climate predictability and change in his global eddy-resolving ocean models. A third project funded by NASA seeks to identify climate changes in the ocean using satellite data and model output.

With funding from the National Science Foundation, two global 1/4-degree simulations were made by Professor Semtner and Dr. Tokmakian using an improved form of an earlier model and with the best available atmospheric forcing. In addi-

tion, satellite altimeter data were used to force the second run, so as to reconstruct the detailed turbulent global circulation of 1992-1996.

Professors J.L. McClean and A.J. Semtner, Jr., sponsored by NSF as part of the analysis and modeling phase of the World Ocean Circulation Experiment (WOCE), have performed extensive analyses of the 1/6-degree Parallel Ocean Program (POP) model both globally and in specific basins. Particular emphasis was placed on the comparison of results from WOCE and POP.

Professors W. Maslowski, Y. Zhang and Semtner, in an on-going study have developed a coupled ice-ocean model of the Arctic at resolution of 18 km and 30 levels. The model will use increasingly high resolution in three dimensions and employ high-quality parameterizations of surface exchanges, ice dynamics, near-surface mixing, deep convection, and topographic interactions. An eddy-resolving simulation of 200 years has been completed, and it will continue including implementation of a 9-km and 40 level grid. The significance of this research lies in better understanding of the Arctic Ocean as a physical system, enabling applications to biological, geochemical, and climate problems, and in the practical predictive capability of clearly exceeding what is presently available. The sponsor is NSF.

Professors Maslowski and Semtner received a grant from Cray Research, Inc., to conduct Arctic Ocean research on massively parallel computers. A successful 200-year simulation was conducted on a T3D machine in Alaska.

MARINE OPERATIONS

Mr. P. Jessen and Professor R.H. Bourke managed shipboard support for NPS at-sea instruction and research projects off the central California coast. Twenty-four days of operations were carried out on the Research Vessel (R/V) *Pt. Sur*. Students and faculty participated in these shipboard projects from both the Departments of Oceanography and Meteorology. The sponsor for this project is the Commander, Naval Oceanography Command. NPS acquired the Point Sur SOSUS array and it is being used in a variety of sponsored research projects.

Professor J. R. Clynch conducted several studies in the application of the Global Positioning System (GPS) to DoD applications. For NISE-West he designed and validated a differential GPS system that can be used on an aircraft of opportunity to calibrate the operations of Precision Approach Landing Radars (PARs). In addition, he supported NISE-West in the planning for installation of a DGPS landing system in Antarctica. For the Defense Mapping Agency, he studied methods of improving solutions from military GPS receivers to geodetic quality.